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OZONE INJURY AND HEIGHT GROWTH OF PLANTED PONDEROSA PINES ON THE SEQUOIA NATIONAL FOREST

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ABSTRACT

Ozone injury to pines was first discovered in the southern Sierra Nevada in 1970. Symptoms are now widespread on the Sierra and Sequoia National Forests, yet little is known about ozone's effects at present injury levels. To determine whether height growth of young ponderosa pines is related to severity of symptoms, I surveyed five plantations on the Hume Lake Ranger District of the Sequoia National Forest in 1978. Ozone had been monitored nearby since 1976, and reached the highest levels to date in the year before the survey. Almost one-half of the trees in the plantations had ozone injury symptoms, and about 15% were injured on second-year needles; symptoms on current-year needles were very rare, however. I examined two ozone injury rating systems, and found that the severity of needle symptoms was unrelated to height growth at present injury levels. Although the pines declined in height growth in 1977 and 1978, the 1976-77 drought, brush competition, and insect injury probably masked whatever effects ozone may have had. At current pollutant levels in the southern Sierra, ozone does not appear to be an overriding concern in young plantations. Since these pines have been exposed to excess ozone for a few years only, the long-term effects of this exposure are still not known.

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Ozone injury to ponderosa pines was first seen in the southern Sierra Nevada in 1970 (Miller and Millecan 1971), some 20 years after its discovery in the mountains northeast of Los Angeles (Parmeter et al. 1962). Since then, several surveys (Williams et al. 1977, Pronos et al. 1978, Pronos and Vogler 1981) have demonstrated that injury symptoms on both ponderosa and Jeffrey pines are widespread in the southern Sierra, and some individual trees appear to be severely injured. To date, no mortality has been attributed to ozone. Monitoring at several sites in the affected forests (Vogler 1982) has shown that ozone levels are high enough to injure susceptible conifers, although well below those measured in southern California forests.

The prevalence of ozone injury in the southern Sierra is alarming, but without documented evidence of loss -- either as growth reduction or tree mortality -- foresters have not become greatly concerned. To determine whether current injury levels indicate a measurable growth loss, I conducted a survey of 13-14 year old ponderosa pines in five plantations on the Sequoia National Forest in 1978. My objectives were three:

- to measure the extent and severity of ozone injury symptoms within the five plantations;
- to examine two ozone injury rating systems and determine whether severity of injury was correlated with reduced height growth;
- to measure several site and pest variables to determine how they related to possible reductions in growth.

Young plantation pines were chosen in preference to trees in natural stands because they were even-aged, comprised a broad genetic base, grew under fairly uniform conditions, and were easily accessible for height growth measurements.

METHODS

The study sites are five stands of ponderosa pines planted in 1964 and 1965, and located within a one-mile radius in the Dry Creek drainage of the Hume Lake Ranger District, Sequoia National Forest (T.14S., R.28E., Sections 19, 20, and 29). The plantations lie between 1240 and 1505 m (4070 and 4940 ft) elevation and range in area from 14 to 23 h (35 to 57 ac), as shown in Table 1. They are close to where injury symptoms were first found in the southern Sierra, and are two miles west of Whitaker Forest, where an ozone monitor has operated continuously since July, 1976.

In each plantation, sample plots were selected by systematic sampling with two random starts. Plots were located on aerial color transparencies by twice placing over the photographs a grid representing 100 m (328 ft) on a side, and marking each plot at the intersections of the grid. Each plot was a 5 m (16.4 ft) radius circle, large enough to contain an average of five pines, with at least 30 plots per plantation.

Table 1. Characteristics of five ponderosa pine plantations examined for ozone injury on the Hume Lake Ranger District, Sequoia National Forest, in 1978.

PLANTATION	AREA	PLOTS[a] (No.)	TREES[b] (No.)	YEAR PLANTED	TREATMENTS[c]
Grouse Meadow	19.2 h (48 ac)	41	255	1965	Release(68)/thin(74)
Dry Creek	15.2 h (38 ac)	39	167	1964	Release(68)/thin(74)
Buckman Mill	21.2 h (53 ac)	39	174	1965	
Hyde Mill	14.0 h (35 ac)	51	196	1964	
Red Hill	22.8 h (57 ac)	43	195	1964	Release(68)/thin(74)

[a] Total number of 5 m (16.4 ft) radius plots, comprising a 2% sample of the area of each plantation.

[b] 987 trees total, mean of 4.6 trees/plot.

[c] Release from brush was by herbicide spray; thinning was to establish approximately 3 m x 3 m (9.8 ft x 9.8 ft) spacing.

The color transparencies were used in stereo pairs to locate plots in the field.

Between August 15 and September 15, 1978, a forestry aid and I collected the following site data: altitude, percent slope, aspect in degrees, and percent brush, grass, and barren ground. The vegetational tier beneath the pines totalled 100%, and each brush species was rated as covering a portion of that area to the nearest five percent. Ground heavily eroded or devoid of vegetation comprised the barren component.

For each pine, we recorded d.b.h., total height, height of each of the last five internodes, ozone injury score (Miller 1973), ozone symptom rating, and presence of insect and disease pests. The symptom of ozone injury was a diffuse chlorotic mottle on both upper and lower needle surfaces, spreading from the needle tip downward and affecting the oldest needle whorls first (Miller et al. 1963, Miller and Evans 1974).

The ozone injury score (OIS) was developed to rate pines in the San Bernardino Mountains of southern California, where ozone injury is more prevalent and severe than in the southern Sierra. The OIS is the sum of needle retention and needle symptom ratings for both lower and upper crown, plus scores of 0 or 1 for needle length in each half of the crown and for branch mortality. Needle retention includes only those internodes of needles in which one-third or more will remain attached through the winter. Each year's needles are rated as follows: 4 = healthy,

green; 2 = chlorotic mottle present; 0 = yellow, wholly mottled. Total scores range from 0 to 63, and are divided into several injury categories (Table 2).

Table 2. Severity categories of the ozone injury score [OIS (Miller 1973)].

RANGE OF SCORES	INJURY SEVERITY
36-63	No injury
29-35	Very slight injury
22-28	Slight injury
15-21	Moderate injury
9-14	Severe injury
1-8	Very severe injury
0	Dead

The ozone symptom rating (OSR) ranges from 0 (no injury) to 5 (very severe injury) in each half of the crown, and scores all visible needles by internode (Table 3). The OSR focuses on the severity of needle symptoms alone; if no ozone symptoms are present, the tree receives a 0 rating (no injury), without regard to its general state of health. By contrast, the OIS is a generalized score that emphasizes the overall level of tree decline, assuming ozone to be a major influence on tree vigor.

Table 3. Severity categories of the ozone symptom rating (OSR).

SYMPTOM RATINGS	SYMPTOM SEVERITY
0	No symptoms on any year's needles
1	On 5th-year or older needles
2	On 4th-year and older needles
3	On 3rd-year and older needles
4	On 2nd-year and older needles
5	On current-year and older needles

RESULTS AND DISCUSSION

In the five plantations we examined 987 pines on 213 plots. The results that follow describe the severity of ozone injury in each plantation and overall, trends in height growth over five years, and the relations between height growth and ozone injury, needle retention, needle and branch pests, and brush competition.

EXTENT AND SEVERITY OF INJURY SYMPTOMS

The ozone injury score (OIS) and the symptom rating (OSR) both show that the extent of injury was similar in each of the plantations, and that somewhat more than half of the trees were unaffected (Tables 4 and 5). However, the two systems differ in how they rated the severity of injury. The ozone injury score (Table 4) indicates that about 95% of the trees were no more than slightly injured, only two trees were

Table 4. Percent of ponderosa pines by ozone injury score (OIS) for each of five plantations surveyed in 1978.

	PERCENT OF PINES BY OIS				
PLANTATION	36+ (None)	29-35 (Very Slight)	22-28 (Slight)	15-21 (Moderate)	9-14 (Severe)
Grouse Meadow	67.7	18.8	10.2	4.3	0.0
Dry Creek	43.7	36.5	16.8	3.0	0.0
Buckman Mill	55.7	26.4	14.4	2.9	0.6
Hyde Mill	59.2	25.0	12.2	3.1	0.5
Red Hill	51.8	23.1	19.0	6.1	0.0
TOTAL	56.4	25.2	14.2	4.0	0.2

Table 5. Percent of ponderosa pines by ozone symptom rating (OSR) in the lower crown for each of five plantations surveyed in 1978. [Symptom rating is shown for the lower crown only, as upper and lower crown ratings were strongly correlated (Kendall's tau = .93, P = .01).]

	PERCENT OF PINES BY OSR					
PLANTATION	0 (None)	1 (V.Slight)	2 (Slight)	3 (Moderate)	4 (Severe)	5 (V.Severe)
Grouse Meadow	62.0	12.9	7.5	8.2	9.4	0.0
Dry Creek	55.1	12.6	9.0	12.5	10.8	0.0
Buckman Mill	47.7	10.3	8.1	13.2	20.1	0.6
Hyde Mill	48.5	6.1	9.7	16.8	18.9	0.0
Red Hill	42.1	17.4	15.4	9.2	15.9	0.0
TOTAL	51.7	12.0	9.8	11.7	14.7	0.1

severely injured, and none were very severely injured. Based on this score alone, ozone injury was present but probably not damaging.

The ozone symptom rating (Table 5) -- which records the youngest needles on which symptoms are present -- shows that a quarter of the trees were moderately to severely injured (symptoms on second- and third-year needles). Only one tree, however, was very severely injured (symptoms on current-year needles). Table 6 indicates why the OSR estimates a greater amount of injury than the OIS. Most trees retained three or four years of needles, but a substantial number of these same trees had moderate to severe symptoms. Despite adequate needle retention, these trees were symptomatic, and may suffer worse injury and greater needle loss if ozone levels remain the same or increase.

Table 6. Number of ponderosa pines by years of needle retention in relation to ozone symptom rating (OSR) in the lower crown at plantations on the Sequoia National Forest in 1978 (n = 987 trees).

	NUMBER OF PINES BY YEARS OF NEEDLE RETENTION					
OSR	6	5	4	3	2	1
None (0)	3	94	247	131	33	2
V. Slight (1)	0	23	72	19	4	0
Slight (2)	0	7	43	43	4	0
Moderate (3)	0	6	60	38	12	0
Severe (4)	0	5	46	67	25	2
V. Severe (5)	0	0	0	1	0	0
TOTAL	3	135	468	299	78	4
(Percent)	0.3	13.7	47.4	30.3	7.9	0.4

$Chi^2 = 107.3$, df = 25, $P < .01$
Kendall's tau = -.20, $P < .01$

The OSR may actually underestimate the severity of injury, for it is not possible to rate older needles on trees with three years or less retention. Some trees with few needles were rated as symptomless (Table 6); if we had examined the older needles before they fell, we would probably have found symptoms on many. In fact, when we compare the ratings of symptomatic trees with their years of needle retention, the negative correlation is improved (Kendall's tau = -.30, $P < .01$; n = 477 trees). The correlation between symptom rating and years of needle retention

might have been stronger if the trees had been rated earlier in the season when more injured needles were still attached.

TRENDS IN HEIGHT GROWTH, 1974 TO 1978

In 1978 the mean height of the plantation pines was 3.41 m (11.2 ft) [standard error (S.E.) = 0.13 m (0.4 ft)]. During 1977 and 1978 the pines grew substantially less in height than they grew in 1974-1976 (Table 7). Possible causes of this growth loss include the 1976-1977 drought, increased brush competition, stress-related pest attacks, and ozone injury. In 1977, ozone levels were the highest recorded to date at nearby Whitaker Forest (Vogler 1982), leading one to suspect that ozone contributed to the 1978 growth loss. Based on rainfall data from Grant Grove (NOAA 1977), 1977 was also the second driest year of the drought, possibly obscuring the effects of ozone with those of severe moisture stress. While focusing on the possible role of ozone in this decline, I will also consider the other factors in the results that follow.

Table 7. Annual height growth of ponderosa pines in five plantations from 1974 through 1978.

YEAR	HEIGHT GROWTH ±99% CONFIDENCE LIMITS Centimeters	(Inches)
1974	36.2±1.5	(14.2±0.6)
1975	36.8±1.5	(14.5±0.6)
1976	34.3±1.5	(13.5±0.6)
1977	21.6±1.1	(8.5±0.4)
1978	15.3±0.9	(6.0±0.4)

RELATION OF HEIGHT GROWTH TO INJURY SYMPTOMS

Table 8 illustrates the relations between the two ozone injury rating systems and 1978 height growth. Because the ozone systems rank injury on an ordinal scale, nonparametric statistics were used to calculate the correlation coefficients (Siegel 1956).

The ozone symptom rating (OSR) shows no correlation with height growth, but is moderately correlated with the ozone injury score (OIS). The OIS correlates weakly with growth but strongly with needle retention.

Since the OIS is derived mainly from the sum of symptom ratings and years of needle retention, and since the OSR shows no correlation with growth, it seems likely that most of the strength of the OIS is

Table 8. Matrix of rank-order correlation coefficients (Kendall's tau) between needle retention, ozone injury, and 1978 height growth. (GROW78 = height growth in 1978; NRL = needle retention in lower crown; OSR = ozone symptom rating; OIS = ozone injury score.)

	CORRELATION COEFFICIENTS[a]			
	GROW78	NRL	OSR	OIS
GROW78	1.00			
NRL	.35	1.00		
OSR	-.06	-.20	1.00	
OIS	.29	.74	-.45	1.00

[a]Significance: $P < .01$.

contributed by needle retention. The Kendall partial rank correlation coefficient (Siegel 1956) confirms this. When the influence of needle retention on the relation between growth and the OIS is removed, the relationship disappears ($tau_{xy.z} = .05$; no test for significance).

In short, only needle retention is related to growth. The severity of needle symptoms is unrelated to height growth loss at present injury levels. However, too few pines had symptoms on current year's needles to say with certainty that severe symptoms and growth loss are unrelated. Furthermore, we do not know what relation may exist between present symptoms and growth loss in future years. The negative correlation between the OSR and needle retention suggests that severe ozone symptoms may lead to increased needle loss in these plantations.

RELATION OF HEIGHT GROWTH TO SITE AND PEST VARIABLES

Whatever injury ozone, as evidenced by needle symptoms, may cause in these plantations, there are other factors that may be more important in reducing growth (Table 9). Because these variables were measured on an interval scale, they were analysed by parametric statistical methods; correlations were improved by using the natural logarithm of height growth.

Several characteristics of site -- slope, aspect, and elevation -- were uncorrelated with height growth. A categorical scoring of topography (from ridge top to stream bottom) was likewise uncorrelated (Kendall's tau = .06, P = .01).

Needle pests -- including aphids, scale, a Scythropus sp., and an unknown needle feeder -- appeared unrelated to growth (Table 9) or to needle retention (r = -.06). However, their effects may not become

Table 9. Characteristics of pest and site variables and their correlations with 1978 height growth (natural log transformation) of ponderosa pines in five plantations (n = 987 trees).

VARIABLE	MEAN	S.E.	RANGE (Min-Max)	CORRELATION WITH GROWTH IN 1978 (Pearson's r)
NEEDLE RETENTION	3.7	.0+	1-6	.45*
NEEDLE PEST SCORE	1.2	.0+	0-6	.01
BRANCH PEST SCORE	1.5	.1	0-7	-.36*
SLOPE (%)	27.3	.3	5-50	.09*
ASPECT (Cosine)[a]	.1	.0+	-1-+1	-.01
ELEVATION (m)	1409.1	1.6	1240-1505	.04
MANZANITA (%)	42.6	.6	0-100	-.24*
BEAR CLOVER (%)	12.6	.4	0-60	-.07
CEANOTHUS (%)	8.1	.4	0-45	-.11*
RIBES (%)	8.0	.3	0-60	.20*
OTHER BRUSH[b] (%)	4.6	.3	0-65	.09*
BARREN (%)	5.9	.3	0-100	-.12*
BRUSH-BARREN[c]	73.7	22.8	0-100	-.34*

*Significance: $P < .01$.

[a] Aspect was transformed [= cosine (aspect + 15^{o})] so that the harshest aspect (195 degrees) would be penalty-rated -1.

[b] Included oak, choke cherry, coffeeberry, mountain mahogany, elderberry, bitterbrush, poison oak, rose, mullein, fern, lupine, yerba santa, and thistle.

[c] Included manzanita, bear clover, ceanothus, other brush species, and barren ground.

evident until after several years of successive attacks. The severity of injury by branch pests [the gouty pitch midge (Cecidomyia piniinopis) and an unknown twig weevil] correlated moderately with growth and slightly with needle retention (r = -.23). Disease pests were rare in

the plantations; western dwarf mistletoe (Arceuthobium campylopodum) was common in the surrounding stands, but only one tree on the plots was infected.

Several brush species were evaluated separately. Although manzanita, bear clover, ceanothus, and barren ground were all weakly correlated with height growth, the combination of manzanita, bear clover, ceanothus, minor brush species, and barren ground was a stronger indicator of competition with the pines.

Multiple regression of height growth in 1978 with the strongest variables from Table 9 yields the following equation:

Log-normal GROW78 = 2.07 + (.33 NRL) - (.01 BRUSH) - (.13 BRANCH PESTS).

Although the model accounts for only 33% of the variability in the sample (r-squared = .333), it includes most of the major factors which the survey examined. Brush competition is an established cause of growth loss and mortality in plantations, and predisposes stressed trees to attack by branch-feeding insects. Needle retention, although it may be as much an effect as a cause of poor growth, is an excellent indicator of tree vigor. Missing is ozone injury, which at present injury levels does not appear to be important. Ozone can reduce needle retention, but this cannot be verified without observing the loss of visibly-injured needles in subsequent years.

Another cause of growth loss may have been the 1976-1977 drought. The added moisture stress would have made brush competition more severe, predisposed the trees to insect attack, and directly reduced needle retention. Lastly, the drought also created hot, rain-free summers that contributed to higher ozone levels than have been recorded in the southern Sierra to date.

CONCLUSIONS

The survey did not substantiate ozone as a major cause of growth loss in pine plantations in the southern Sierra. It did, however, lead to several conclusions that must be considered in on-going and future evaluations of ozone injury to conifers.

- As in surrounding forest stands, ozone injury is common on plantation pines. Somewhat less than half of the trees had symptoms, and about 15% were injured on second year's needles; symptoms on current year's needles were very rare.

- The extent of ozone symptoms on needles is not related to height growth at present injury severity.

- The ozone injury score (OIS) combines ratings for needle retention and ozone symptoms, and tends to obscure the possible causes of growth loss. A low score (greater injury) may be the result of poor needle retention caused by factors other than ozone; on the other hand, a high score (less

injury) may mask the presence of moderate-to-severe injury symptoms on trees with adequate needle retention.

- The OIS was developed in southern California forests where ozone levels are extremely high and most trees have symptoms. In the southern Sierra, where ozone levels are lower and injury less common, a system like the ozone symptom rating (OSR), which records the presence and severity of symptoms, is preferable.

- The OSR is less meaningful if needle retention is not recorded also. A tree with no symptoms and one or two years needles is not necessarily uninjured; evidence for ozone injury is merely lacking.

- At current pollutant levels in the southern Sierra, ozone does not appear to be an overriding concern in young plantations. Drought, brush competition, and insect pests have so masked the effects of ozone that they are not now apparent. When forest management becomes more intensive, the effects of ozone may become more obvious.

- Since the trees in these plantations have been exposed to excess ozone for a few years only, the long-term effects are not known. Continued monitoring of symptom development and the possible delayed effects of visible injury are essential.

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